



# Hydrogen-Oxygen PEM Regenerative Fuel Cell Energy Storage System

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# **Hydrogen-Oxygen PEM Regenerative Fuel Cell Energy Storage System**

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## **Summary**

An introduction to the closed cycle hydrogen-oxygen polymer electrolyte membrane (PEM) regenerative fuel cell (RFC), recently constructed at NASA Glenn Research Center, is presented. Illustrated with explanatory graphics and figures, this report outlines the engineering motivations for the RFC as a solar energy storage device, the system requirements, layout and hardware detail of the RFC unit at NASA Glenn, the construction history, and test experience accumulated to date with this unit.

## **Introduction**

The PEM hydrogen-oxygen regenerative fuel cell system is potentially the highest storage capacity and lowest weight non-nuclear energy storage system for extra-terrestrial applications. A solar array equipped unmanned aerial vehicle (UAV) with a regenerative fuel cell energy storage system, for example, could provide a high altitude platform with theoretically unlimited endurance. This potential led NASA to undertake the practical development of a hydrogen-oxygen regenerative fuel cell, initially as solar energy storage for a high altitude, UAV science platform. At present, the RFC system is programmatically part of the NASA Vehicle Systems Program's Low Emissions Alternative Power (LEAP) Project to further the development of aerospace regenerative fuel cells for high altitude and space missions.

The RFC system was designed to be a completely closed loop test bed for the cyclic operation of fuel cell systems up to 60 kWh (5 kWe X 12 hr). Closed loop means the system with its electrochemical reactants and products is completely sealed; nothing goes into the system other than electrical power and there are no discharges or emissions from the system other than electrical power and waste heat.

The RFC system can accommodate a fuel cell stack up to 5.25 kW (100 A at 52.5 V) capacity. The system has a maximum operating pressure of 400 psig. The electrolyzer operates at the system pressure while the fuel cell reactant feeds are regulated down to 50 psig. A 15 kW (150 A at 100 V) electrolyzer is used to charge the reactant tanks to full pressure while running under a current profile that simulates the output of a solar array during the 12-hr daylight cycle. During the nighttime phase of the solar cycle, the fuel cell runs at constant power for most of the cycle.

A DC power supply simulates the solar input to the electrolyzer and a DC load is used to sink the fuel cell current. The closed loop water supply provides source and cooling water for the electrolyzer, and humidification and discharge collection for the fuel cell.

Data acquisition and control for the RFC is provided by a multithreading suite of NASA Glenn developed software using the National Instruments LabVIEW™ programming language. The safety of

the test facility and hardware is enhanced by an automatic transfer of authority algorithm among the three PCs which are present on the RFC local area network.

Construction of the closed loop system began in 2002 at the NASA Glenn Research Center in Cleveland, Ohio, under the Environmental Research Aircraft and Sensor Technology (ERAST) project. System checkout was completed, and testing began, in July 2003 (ref. 1). The initial test sequences were done with only a fuel cell or electrolyzer in the test rig. Those tests were used to verify the test apparatus, procedures, and software. The first complete cycles of the fully closed loop, regenerative fuel cell system were successfully completed in the following September. Following some hardware upgrades to increase reactant recirculation flow, the test rig was operated at full power in December 2003, and again in January 2004. In March 2004, a newer generation of fuel cell and electrolyzer stacks was substituted for the original hardware and these stacks were successfully tested at full power under cyclic operation in June 2004.

Test experience so far has been limited by the number of multi-kilowatt rated hydrogen-oxygen fuel cell and electrolyzer stacks available, but initial results from these stacks are encouraging. To the best of our knowledge, this test facility is currently the only fully closed loop test facility in the United States for regenerative PEM hydrogen-oxygen fuel cell systems.

Closed loop testing presents both challenges and opportunities which are not present in open loop fuel cell testing. For example, the presence of inert gases in the reactant streams can noticeably degrade the fuel cell performance because the inerts are recycled. Inerts can enter the system whenever it is opened for installation or maintenance, or when commercial bottled gases are used to initially charge the reactant tanks. We have gotten around the problem of inert gas contamination from air/purge gas or commercial gas impurities by venting small amounts of gas from the fuel cell reactant recirculation loops during the first fuel cell cycle. Once the inert gases have been vented, successive cycles can be run with the system fully closed.

Similarly, contamination of the water resources by either mineral leaching or biological growth can degrade performance over time. In addition to a conductivity monitor, the system water loop is equipped with a de-ionizing resin bed, UV lamp and filter train to remove stray contaminants and bacteria. Nevertheless there is still some potential for buildup in other system reservoirs (for example the phase separator tanks). Possible contamination of the water resources from mineral leaching and biological growth is being monitored via chemical analysis of periodic system water samples.

Recombination of the reactant species inside the electrolyzer during shutdown periods has also proven to be a problem. With the source current removed from the electrolyzer, this recombination can cause a large differential pressure across the electrolyzer membranes because, on a per volume basis, the hydrogen is consumed twice as fast as the oxygen. We have implemented a trickle current loop to supply short bursts of low current to the electrolyzer to keep the pressure balanced during this recombination phase.

Finally, we have implemented a comprehensive water management scheme towards the goal of preserving reactant supply, since the reactant loss rate ultimately determines system service interval and lifetime. A set of electronic scales underneath the phase separator tanks allow us to keep a running inventory of the water supply, and a management routine in the control software keeps the operators apprised of the loss rate.

To date we have successfully met the challenges arisen from closed loop operation over successive charge/discharge cycles to 5 kWe power level and 12 hr run time. We anticipate further challenges to arise as we transition from multiple back-to-back test runs to multi-day and longer term continuous operations, in our quest to reduce to practice the operation of this RFC system as an energy storage device.

## Reference

1. Bei-Jiann Chang, Donald W. Johnson, Christopher P. Garcia, Ian J. Jakupka, Vincent J. Scullin, David J. Bents, "Regenerative Fuel Cell Test Rig at Glenn Research Center," NASA/TM—2003-212375.



Figure 1.—Building 135 Regenerative fuel cell test site.



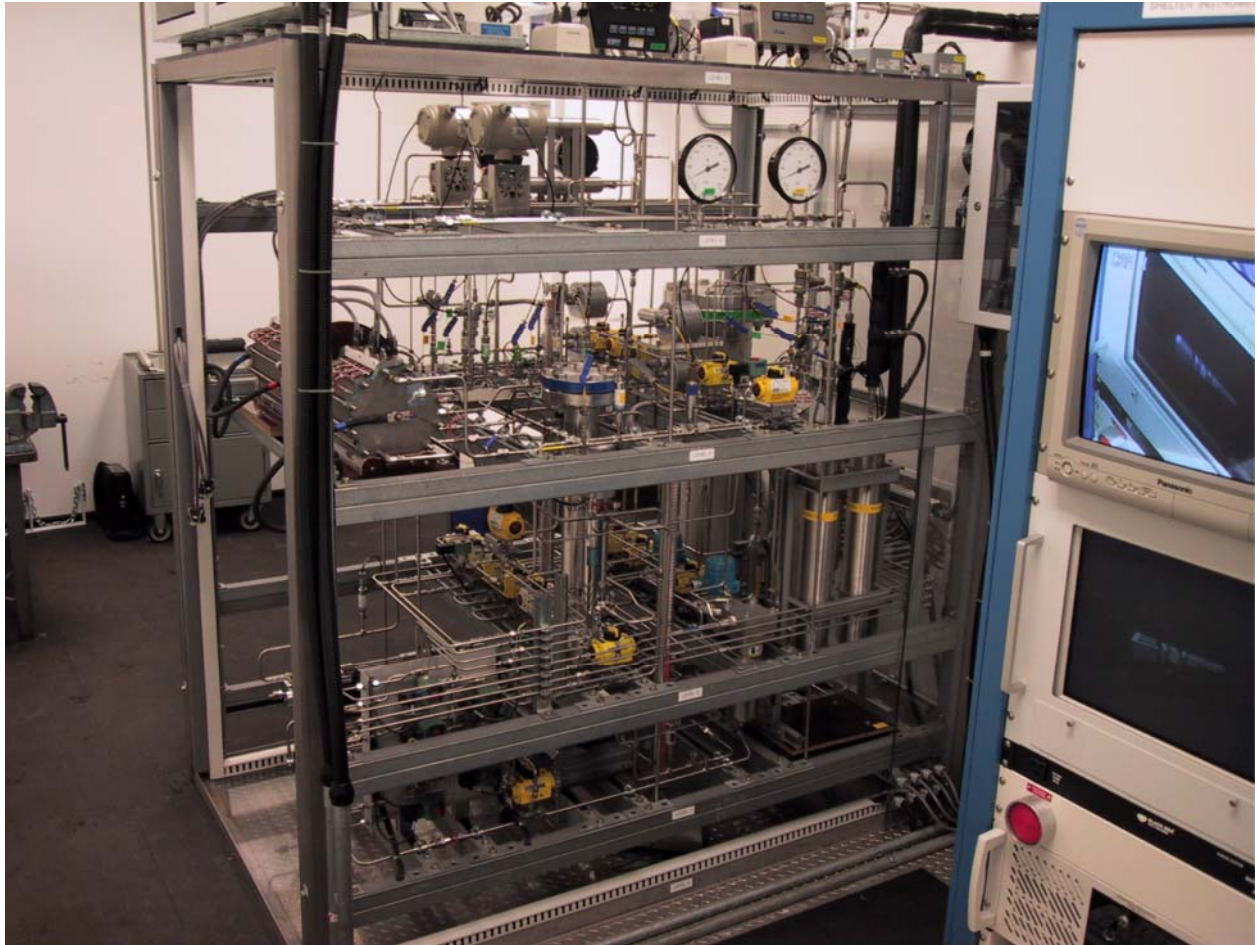


Figure 2.—Integrated equipment assembly inside Building 135 enclosure.



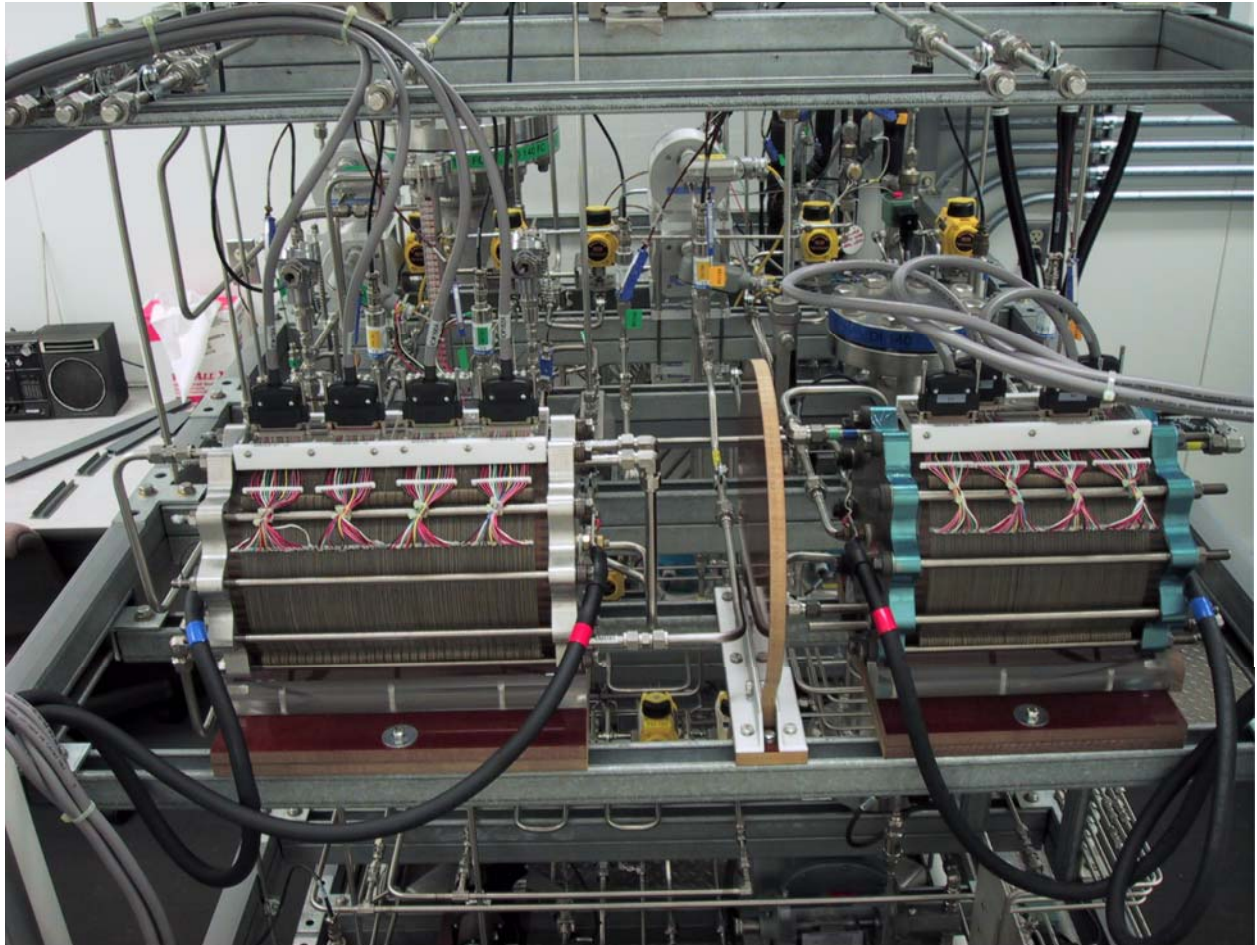


Figure 3.—Integrated equipment assembly: fuel cell and electrolyser stacks.



Figure 4.—Control room.

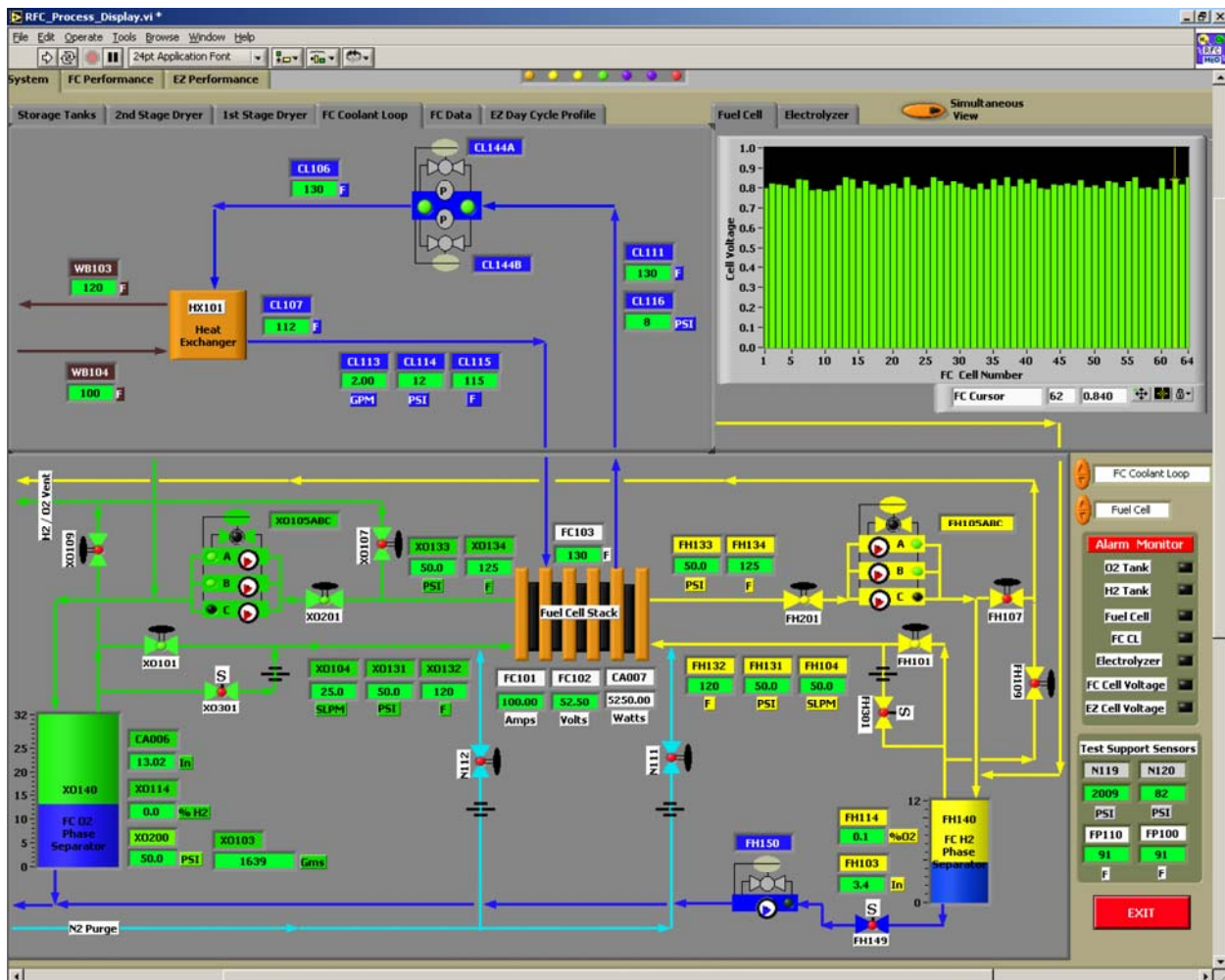


Figure 5.—RFC LabView control screen and process display.





Figure 6.—The gang that built the regenerative fuel cell.



Figure 7.—Electrolyzer stack.

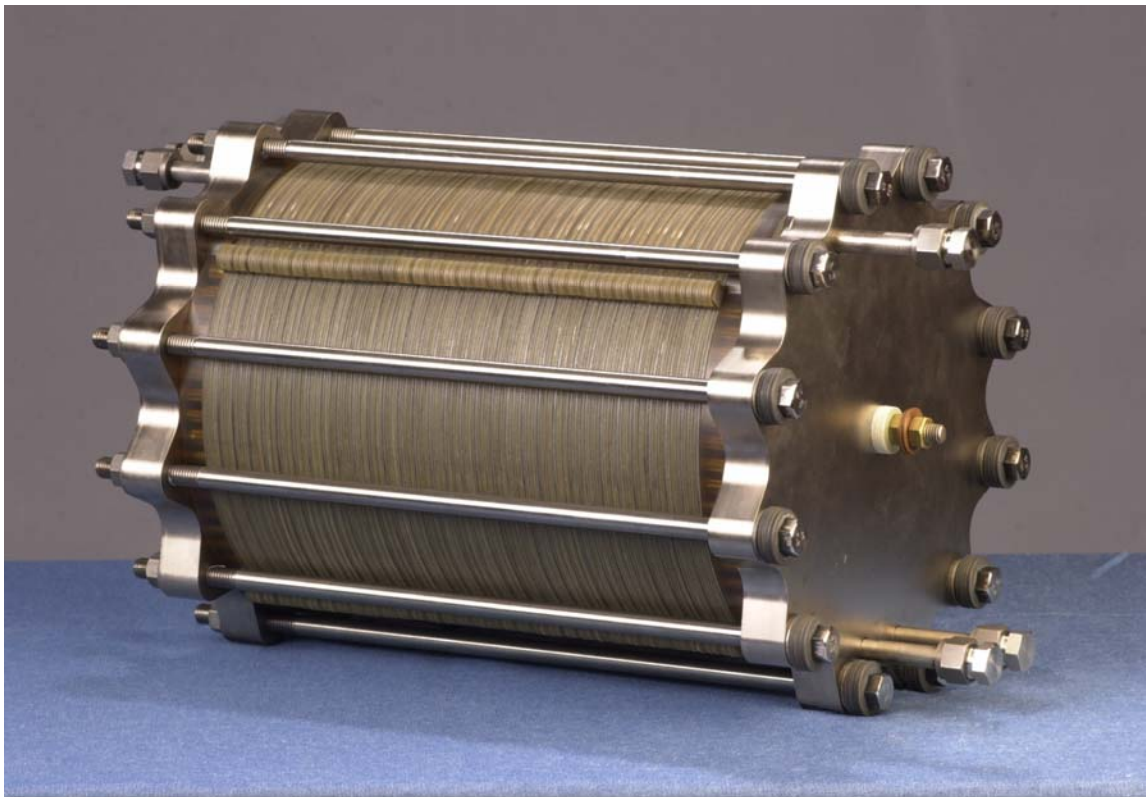


Figure 8.—Fuel cell stack.



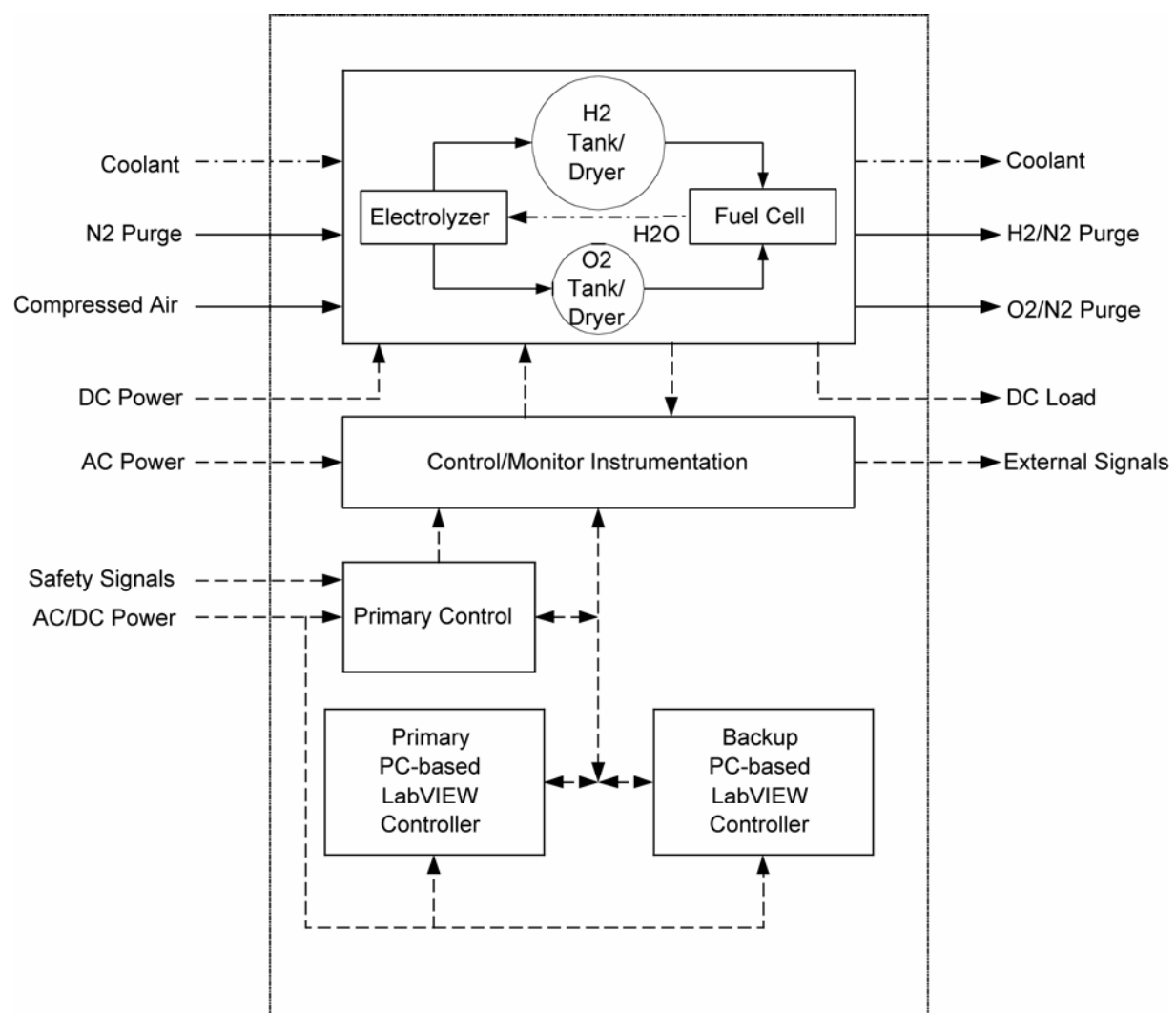


Figure 10.—Regenerative fuel cell test rig process block diagram.



Schematic Symbol	Description	Schematic Symbol	Description
CL 111	Thermocouple, Type T	FH 201	Valve, Ball, Pneumatic
CL 113	Flow Meter, Turbine	FH 202	Pressure Regulator
CL 115	Thermocouple, Type T	FH 203	Scale
CL 144	Pump, Cooling	FH 240	Phase Separator, Hydrogen
CL 144	Pump, Water	HX 101	Heat Exchanger, Shell and Tube
DI 102	Thermocouple, Type T	HX 102	Heat Exchanger, Shell and Tube
DI 110	Flow Meter, Turbine	WB 107	Dryer, First
DI 150	Pump, Transfer	WB 108	Dryer, First
DI 154	Pump, Cooling	WB 109	Dryer, Second
DI 201	Valve, Ball, Pneumatic	WB 110	Dryer, Second
DI 202	Valve, Ball, Pneumatic	XO 103	Scale
EZ 1 - 60	Electrolyzer Cell Voltage tabs	XO 104	Flow Meter, Laminar
EZ 101	Electrolyzer Stack Current shunt	XO 105	Pump, Recirculation
EZ 102	Electrolyzer Stack Voltage	XO 113	Storage Tank, ASME Pressure Vessel
FC 1 - 64	Fuel Cell Cell Voltage tabs	XO 114	Contaminant Sensor
FC 101	Fuel Cell Stack Current shunt	XO 121	Sensor, Level
FC 102	Fuel Cell Stack Voltage	XO 139	Pressure Regulator, Back
FH 104	Flow Meter, Laminar	XO 140	Phase Separator, Oxygen
FH 105	Pump, Recirculation	XO 142	Thermocouple, Type T
FH 113	Storage Tank, ASME Pressure Vessel	XO 201	Valve, Ball, Pneumatic
FH 114	Contaminant Sensor	XO 202	Pressure Regulator
FH 139	Pressure Regulator, Back	XO 203	Scale
FH 140	Phase Separator, Hydrogen	XO 240	Phase Separator, Oxygen
FH 201	Valve, Ball, Pneumatic		

Figure 11.—Regenerative fuel cell—ingredients per schematic.



Figure 12.—Solar electric aircraft.

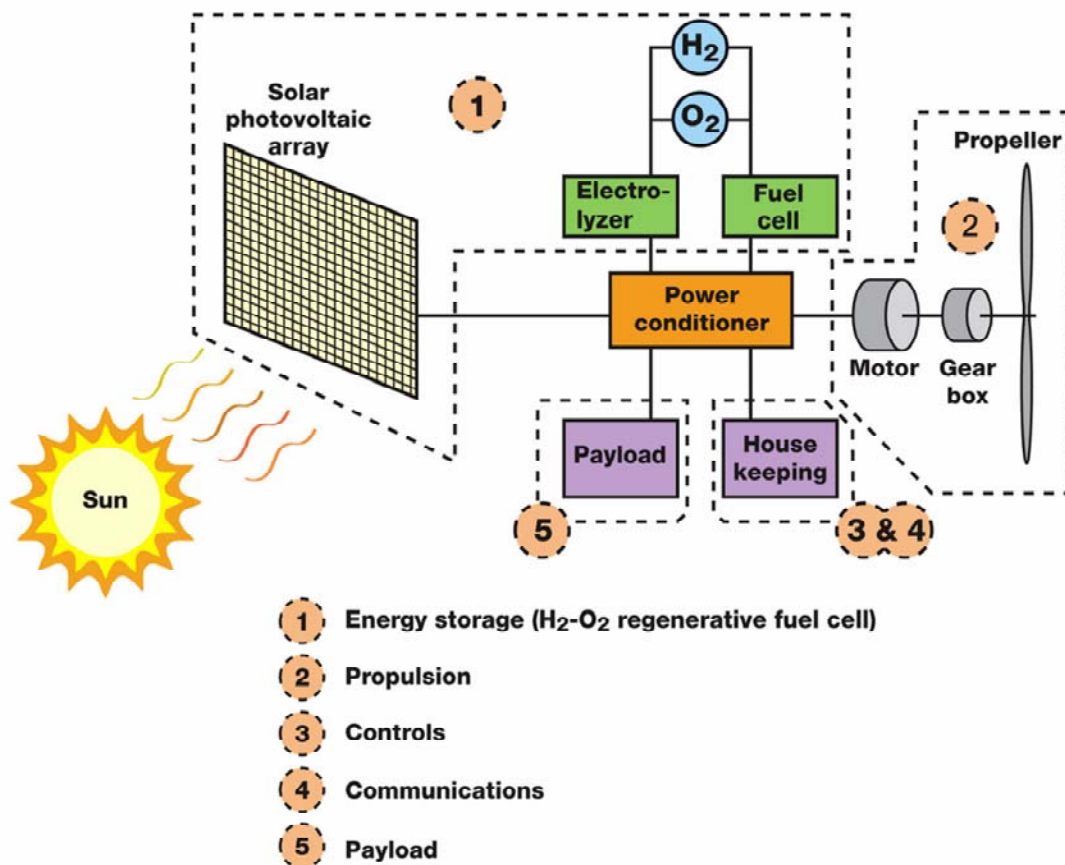


Figure 13.—Solar plane power train.

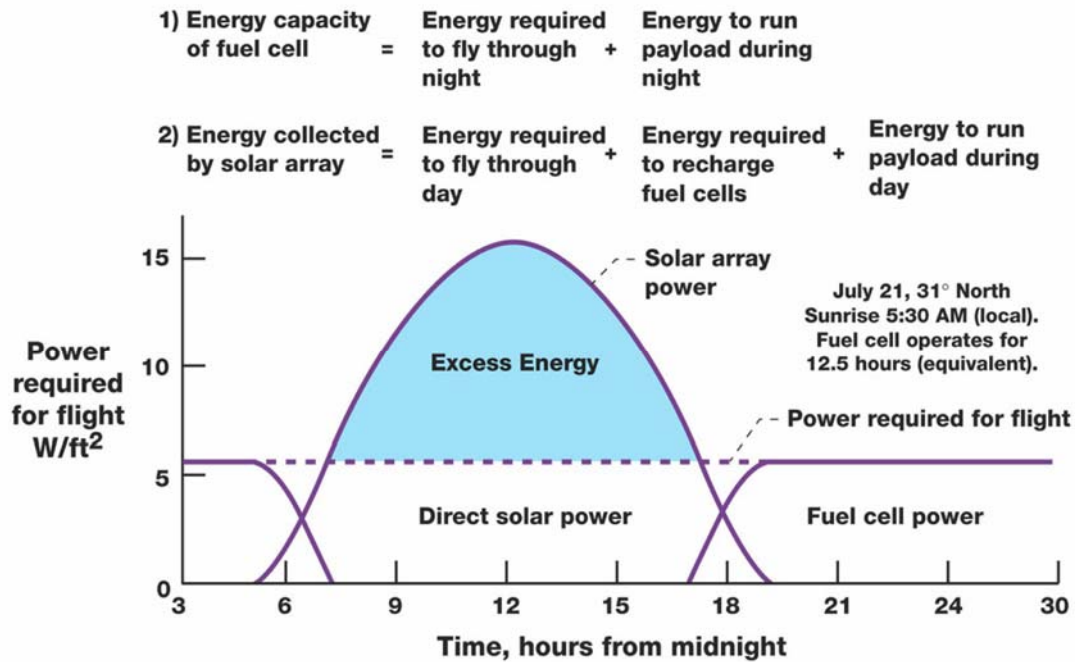


Figure 14.—Energy balance for continuous flight.

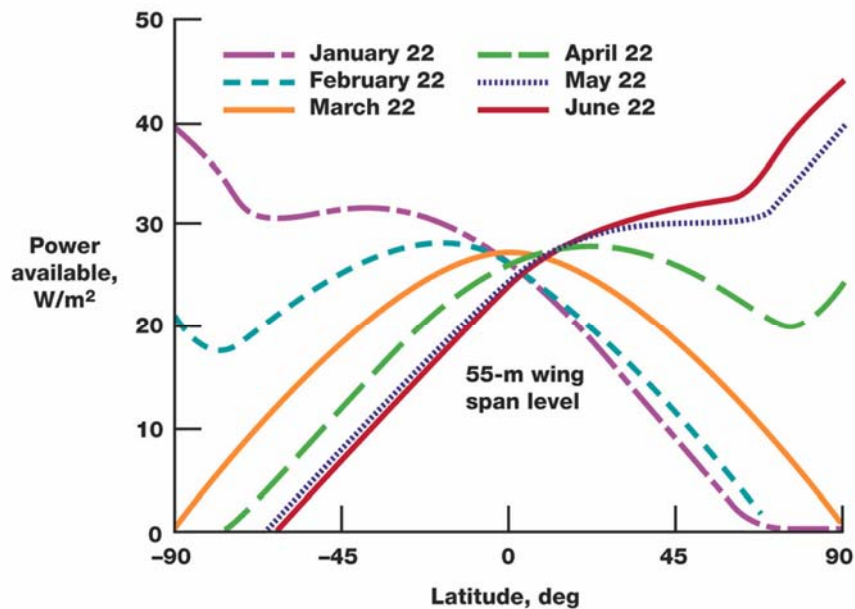


Figure 15.—Solar power available versus earth latitude from January to May.

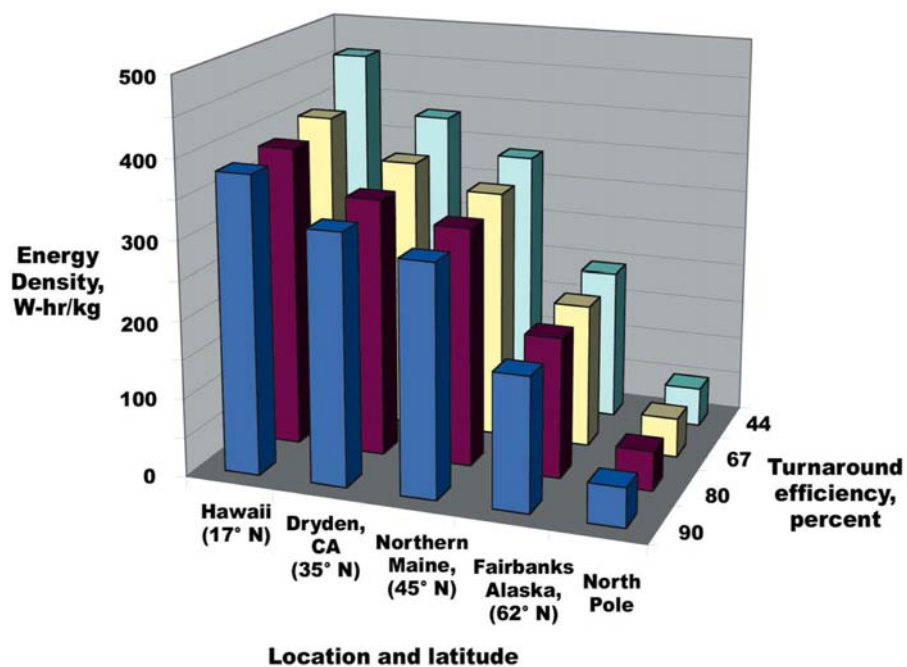


Figure 16.—Energy storage requirements for 30-day continuous flight beginning June 7.

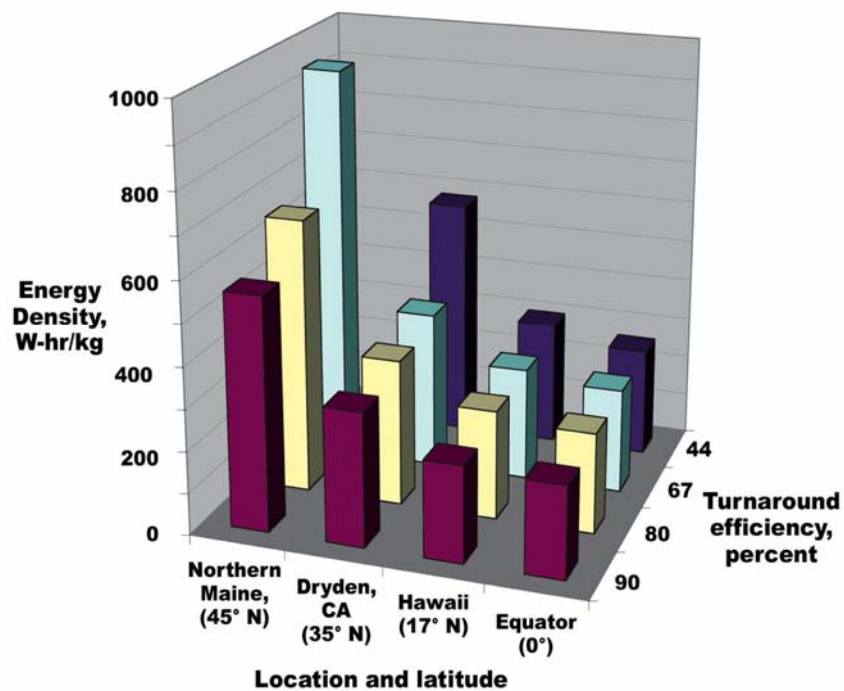


Figure 17.—Energy storage requirements for year-long continuous flight.

### Why we are doing it?

- Key technology that enables future NASA missions
  - Solar energy storage of choice for day/night cycles > 4 hr
- Technical performance appears achievable
  - We can make it happen

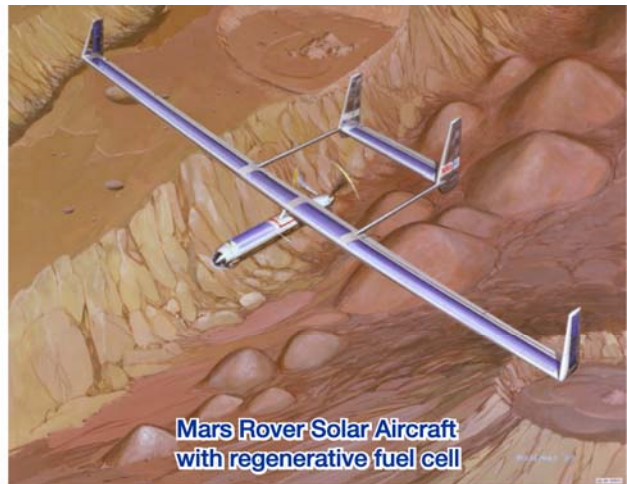


Figure 18.—Why we are doing it?



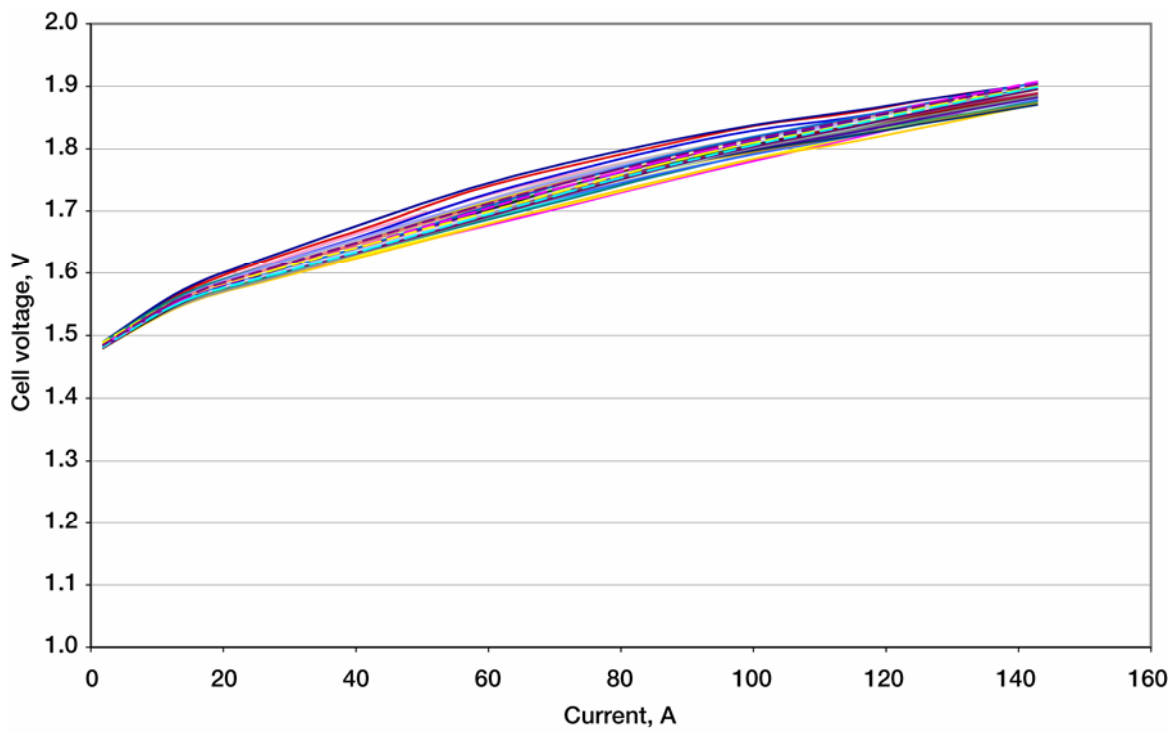


Figure 19.—Votage versus current 150 °F, 380 psig, April 29, 2004.

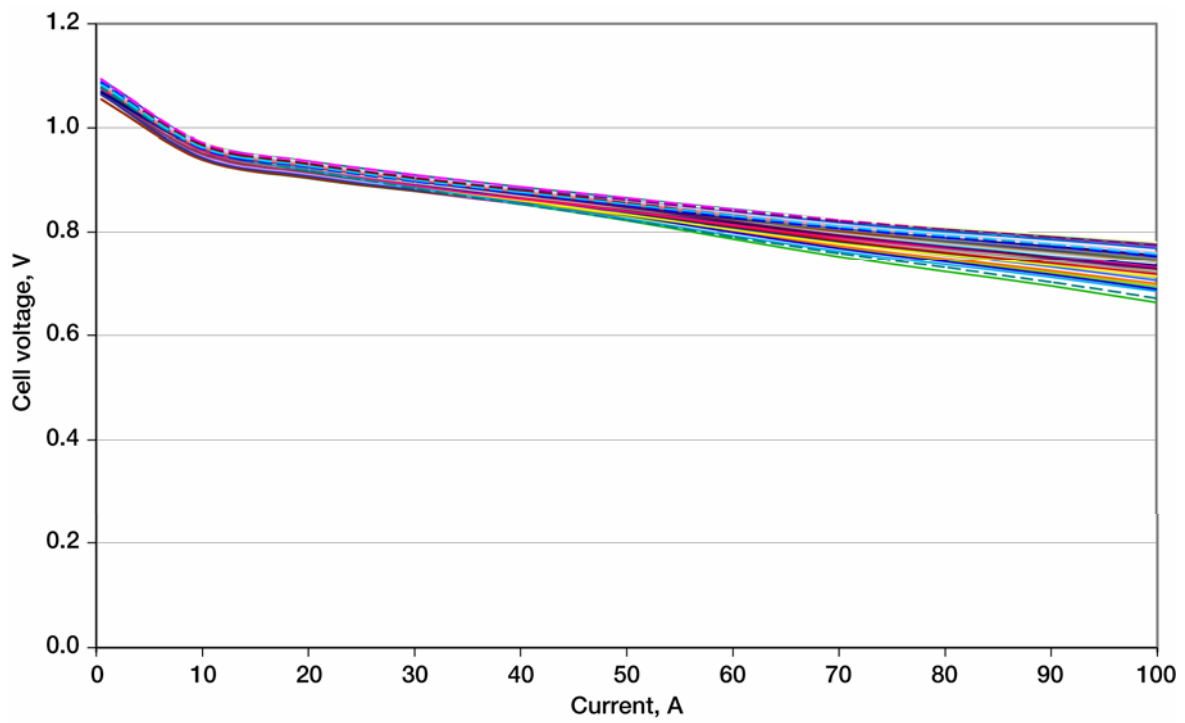


Figure 20.—Fuel cell voltage versus current, June 2, 2004.



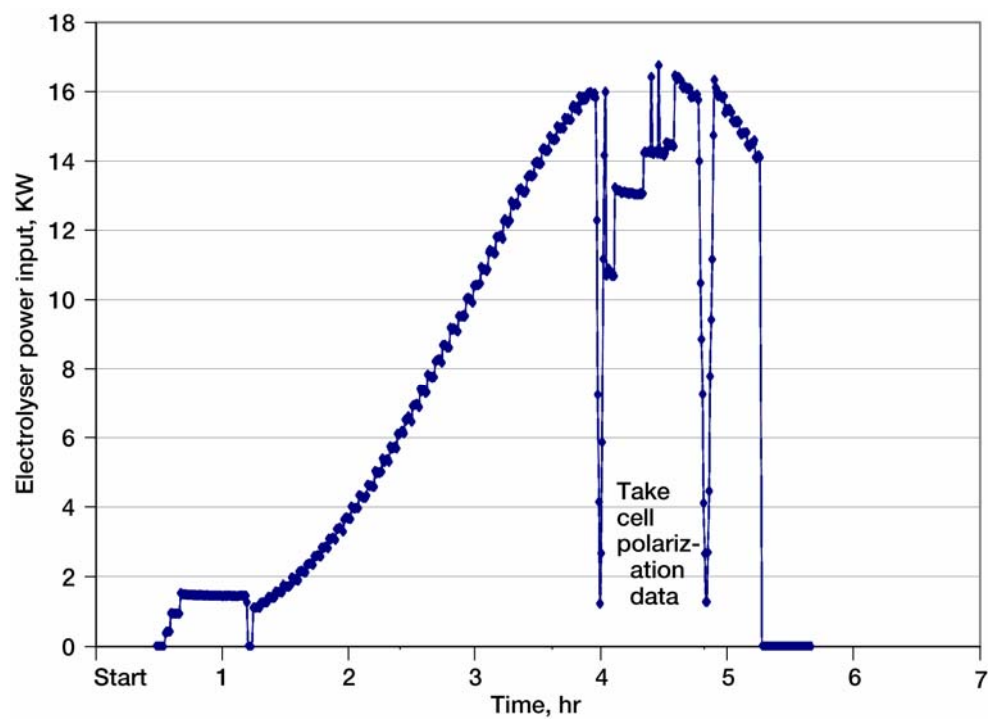


Figure 21.—Solar day cycle.

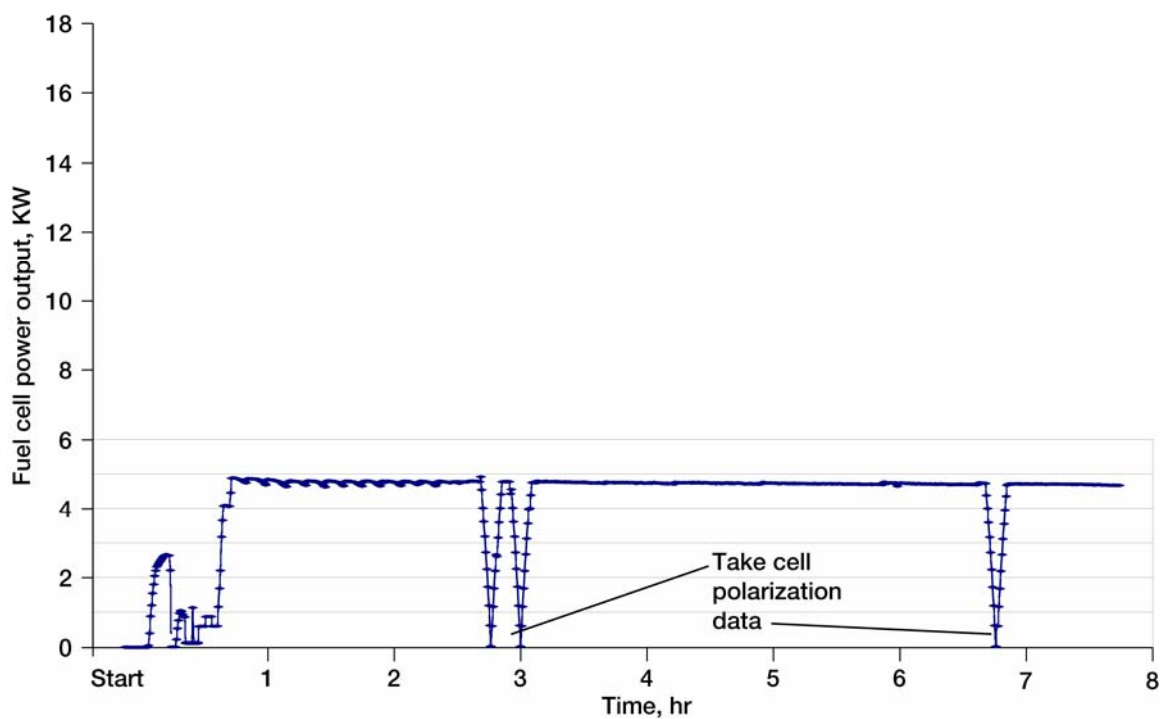


Figure 22.—Solar night cycle.

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